trace-width and trace-separation guidelines according to the board's design to avoid crosstalk. Calculate the parasitic inductances and capacitances between adjacent traces to see if you will encounter any problems at the operating frequency of interest. And for operation at high frequencies, you need to consider the dielectric properties of the pc board's laminate material.

Providing a guard trace along the outer edges of the board and connecting this trace to ground can help to divert any ESD-induced discharge currents that result from human contact to ground. All the precautions you take during production and packing of ESD-sensitive components are pointless if operators carelessly handle and assemble boards. For this ESD problem, you can provide a guard trace by diverting the energy to ground. Provide a voltage-clamping fast-acting device, such as a transient-suppressor diode, at the inputs of sensitive components along with a protective network to reduce damage due to inrush current. Maintain a clean ground with a low impedance to achieve a low noise and interference level.

ESTIMATE THE JUNCTION TEMPERATURE

You can use thermal resistance to estimate the junction temperature of a device if you know the ambient temperature, the thermal resistances of the paths, and the power dissipation. You simply add the $P\times R_\theta$ product, which gives the individual ΔT, and the reference ambient temperature. Mathematically,

$$T_J=T_{AMB}+P\times R_\theta,$$

where T_J is the junction temperature of the device, T_{AMB} is the ambient temperature, P is the power dissipated in the device, and R_θ is the total thermal resistance of the path from the device junction to the ambient. You can obtain the necessary thermal-resistance values from databook specifications and heat-sink catalogs. By computing the power dissipated in the device from circuit-level calculations and substituting the values, you can then calculate the junction temperature of a device at a given load and ambient temperature.

SHIELD THE ENTIRE SYSTEM

As with a single component, you can reduce EMI effects by shielding an electronic system. The principle of shielding is to absorb or reflect the incident electromagnetic or electrostatic field. At low frequencies, absorption of the incident magnetic field is the best method to contain interference, whereas at higher frequencies, reflection of the incident unwanted RFI is the best technique. Reflections result from mismatches in the impedance between the low-impedance metal and the high-impedance wavefront. It causes poor absorption and higher reflection of incident energy.

You can shield against low-frequency electric fields by using a nonmagnetic material such as aluminum or copper because reflection of the incident field is the dominating mode of suppression of the unwanted field. High-permeability materials, such as iron, iron-nickel alloys, mumetal, and permalloy are efficient shielding materials for low-frequency magnetic fields. The permeability of these materials decreases as the frequency increases, and at very high frequencies, these conventional magnetic materials are ineffective shielding materials. Materials such as copper or aluminum are good shielding materials at higher frequencies; they can reflect the incident wave because of the impedance mismatch between the field and the shielding material. High-conductivity materials, such as copper or aluminum, are useful for shielding against electric fields. However, these materials are ineffective for shielding against magnetic fields because reflection loss is insignificant.

It is important to maintain electrical-circuit continuity throughout your enclosure design, including joints. To avoid leakage of the field through radiation effects, any hole in a cabinet should be less than $\lambda/20$, where λ is the wavelength of the signal. In other words, you don't want the hole acting as a slot antenna. Unused connectors can charge, so you should keep them covered with static-dissipative material when you are not using them. All insulating parts in the cabinet should have sufficient dielectric strength to avoid breakdown due to high electric field. Mounting connectors inside a recess helps to avoid accidental contact with charged objects. Cables entering the cabinet should have shields, and the shields should connect to a 360° contact with the cabinet to avoid antenna effects.

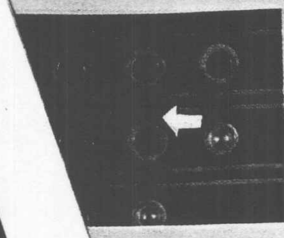
Plastic materials coated with chemicals such as ammonium salts and amidoamines are available for packing sensitive electronic components. ESD control through antistatic flooring is a useful measure. Containers for storing sensitive components are available in the form of conductive plastic bins, trays, tubes, carbon-filled plastics, and metal-foil-lined bags. These bags can be single or multilayered, transparent, or opaque. The opaque bags are made of carbon-filled plastic and are inexpensive and rugged, which makes them sufficient for most ESD-control applications. Metallized-plastic bags, which are also transparent and moisture- and heat-resistant, are durable for storing assembled pc boards.

Conductive fabrics and foam packaging materials are available for fitting around apertures and instrument panels. These I/O-shielding materials offer cost-effective shielding against EMI and ESD. Sources of electric charge in a production set-up include personnel, clothing, computer terminals, synthetic packaging materials, and furniture coverings. Monitoring the handling of components, storage, assembly, testing, and other operations can help prevent ESD-induced damage to electronic devices. Conductive foams, static-dissipative bags, component storage bins, and tubes are also available for storing sensitive components. Place assembled pc boards in static-dissipative bags during storage and shipment. Such containers have a special coating to achieve surface-resistivity requirements, which enable bleed-off of charges that result from the triboelectric effect. The bags also prevent charge accumulation and potential differences between the pins of the device, which can also lead to ESD damage.

PREVENT THERMAL-OVERSTRESS FAILURES

Heat is one of the stress factors that affects all types of components that make up an electronic circuit. To avoid component failures due to excessive heating, you need to take the same care for thermal design as you do for the design of the electronic circuit. Just as current flows in a circuit, temperature flows from junction to ambient (see **sidebar**, "The basic concepts of thermal design"). The junction-temperature limit for semiconductor devices for commercial use is usually approximately 150°C. However, the low-

...-BOARD FAULT



...brication and inspection of ...efore assembly could ... this cat-whisker short and ...ented the consequent failure of the board.

THERMAL-OVERSTRESS FAULT

Mount all components that are likely to become hot during operation on a suitable heat sink to keep junction temperatures low. If the component becomes too hot, it will fail due to thermal overstress, as did this voltage regulator.

... to suffer

...ge occurs in electronic sys- ... as a result of direct or indirect effects. Direct effects include voltage or current surges during operation. In this case, even though a device may be operating within its SOA during normal functioning, the system can impress a larger-than-normal voltage in the form of a spike or transient on the device. Indirect effects occur when a device failure leads to the failure of another device.

EOS can cause the following kinds of damage in commonly used components:

- In semiconductor devices, EOS can lead to junction damage, metallization damage, charring, and damage due to thermal overstress.
- In resistors, EOS can damage the resistive material or result in the melting of the resistive wire in a wirewound resistor or cracking and discoloration.
- In capacitors, EOS can lead to the destruction of the capacitor due to breakdown of the dielectric material or internal heat generation.
- In transformers and coils, EOS can cause the winding to melt, leading to an open or short circuit, which further leads to burnouts or charring of the component due to overheating.

ESD AND EMI

Recently, electronic chip and system designers have taken interest in ESD and EMI. The rapid proliferation of small, portable electronic gadgets, switching power supplies, and wireless transmitters and receivers have increased the problem of ESD and EMI effects. The miniaturization of electronic components has increased the risk factor for failures from ESD and EMI.

ESD occurs because of the transfer of electrons by triboelectric charging—for example, the pins of an IC sliding down a tube charge due to friction. When a charged object or person comes into contact with a conducting surface, electric discharge occurs, causing a temporary large flow of electrons. Such discharges can be fatal to electronic devices if they damage the internal structures.

A simple action, such as a person rubbing his or her hands on a synthetic seat cushion, walking on a carpeted floor, or touching synthetic clothing, can charge that person to a high potential. Higher humidity conditions reduce the effect of static charges by providing a discharge path to ground for accumulated charges. Thus, dry air conditions tend to aggravate ESD problems, and higher humidity conditions reduce charge accumulation.

THE BASIC CONCEPTS OF THERMAL DESIGN

You can model the flow of heat after the current flow in an electrical circuit. The path from the junction of a device through the die and encapsulation to the ambient environment is a series chain of resistances to the transfer of heat, or thermal resistance. In the thermal-network analog to an electrical circuit, temperature is a parameter similar to voltage, thermal resistance is similar to electrical resistance, and power dissipation is similar to current. The ambient temperature is a reference point similar to ground in an electrical circuit.

The unit of thermal resistance, or R_θ, is 8°C/W. If a device's specifications indicate that the thermal resistance from junction to case is 1.2°C/W, the temperature differential between the junction of the device and its case is 1.2°C for a 1W power dissipation.

You can state this relationship between power, temperature, and thermal resistance mathematically:

$$R_\theta = \frac{\text{TEMPERATURE DIFFERENCE (°C)}}{\text{POWER DISSIPATED (W)}} = \frac{\Delta T}{P}.$$

Thus, $\Delta T = P \times R_\theta$°C.

Thermal resistances exist between different interfaces: junction and case, case and heat sink, heat sink and ambient. The thermal resistance from junction to ambient is the sum of the thermal resistances of all the paths involved. Manufacturers' data books give information about the thermal resistance from junction to case and from junction to ambient of a device. The thermal resistance from junction to case depends on the operating currents and voltages of the device and the operating temperature. The interface thermal resistance from case to heat sink depends on the thermal conductivity of the interfacing surface. The thermal resistance of a heat sink varies with its temperature and is lower at higher temperatures.

The objective of good thermal design is to achieve the minimum possible thermal resistance from the junction to the ambient so that heat transfers efficiently from the junction to the ambient.